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Otoendoscopic Visualization of Tympanoscopic Landmarks for Middle Ear Interventions and Robot Assisted Direct Cochlear Access

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Abstract

Introduction

Endoscopy established itself as alternative to traditional (often indirect mirror based) microscopic tympanoscopy and became strongly promoted for various endoscopic middle ear procedures. In order to brigde middle ear and inner ear function by prosthetic surgery, an optimal visualization of important areas of the transition zones between middle and inner ear becomes of special interest; i.e. stapes footplate, round window niche. This study evaluates the potentials of today´s available endoscopic systems for direct transcanal tympanoscopy.

Methods

Under standardized conditions, trained otologists rated independently the degree of visualization (in % area of interest) and the digital image quality (by Visual Analogue Scale) for systematic transcanal tympanoscopy in human formalin fixed temporal bone. In addition to a digital camera and image processing (SPIES, Karl Storz™) the microscopic (Zeiss™), 1.3mm sialendoscopic and 2.7mm otoendoscopic (Karl Storz™) and Chip on Tip (COT) imaging and film data have been used to evaluate transcanal middle ear inspection of microsurgical target structures; especially surgical gateways to the inner ear (e.g. round windown niche for cochlear implant (CI) insertion or stapes footplate for passive and active hearing prosthesis insertion).

Results

Compared with transcanal microscopic inspection, the visualization with endoscopes was rated as more complete for the sinus tympani, facial recess, Eustachian tube orifice, and epitympanum. Digital image processing may help in correction of adverse light effects especially in the Eustachian tube area. For structures out of direct line of sight, best picture quality was achieved by digital and rod lens endoscopy. Optimal results were achieved by the microscope in the regions accessible with straight line of sight only. On the other hand, 45° rod lense endoscopes showed best results for hidden regions with angulated view. Adequate endoscopic visualization of the stapes footplate and the round window niche as well as monitoring of the transtympanic part of robot assisted direct cochlear access in cadaver heads was feasible.

Conclusion

Endoscopes offer a portable and low cost alternative to microscopes for minimal invasive transcanal tympanoscopy and interventions especially in hidden recesses od the middle ear. (i.e. round window niche and stapes footplate for hearing implant surgery or sinus tympani and facial recess to exclude hidden ear disease). Best picture quality was achieved by digital rod lens and the microscope. Digital endoscopic image processing may in the Eustachian tube region improve inspection even in adverse light effects. The microscope showed good results when objects with straight line of sight were inspected. On the other hand, endoscopy may not only improve visualization of many structures and maneuvers by an angled view but provides also for detailed and sharp picture quality. Progress in endoscopic and especially camera chip technology will allow for much smaller scaled tools which can be integrated in robot systems reducing the access paths and thus invasive exposure for interventions. An example of endoscopic visualization for simulated robot assisted CI is given.

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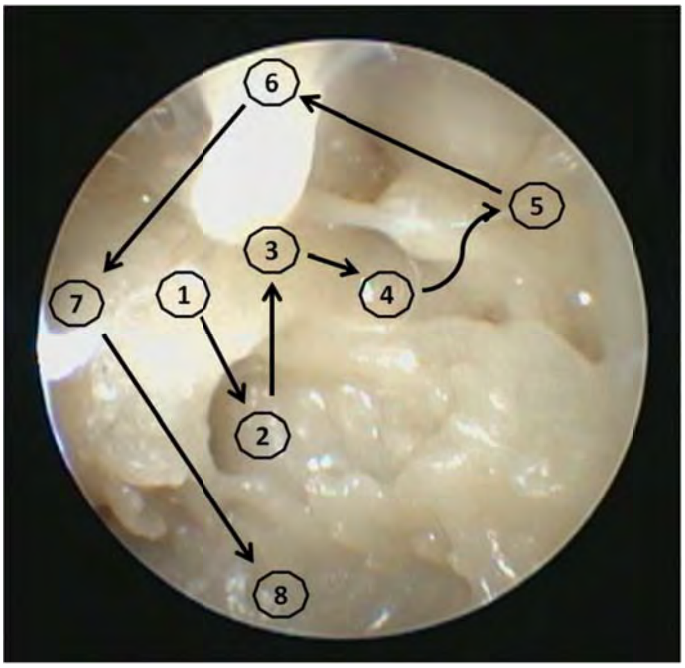
1 Introduction

In order to evaluate the microanatomy of the complex middle ear structures for otosurgery[1], various microscopic techniques (e.g. reversible canal wall down operations) have been proposed[2,3]. Even indirect mirror based[4,5,6] microscopic techniques have been described to compensate for the inherent need of straight line of sight and restriction by the tunnel like view of the microscope. Alternatively, endoscopic systems have been developed to achieve more comprehensive views into hidden anatomical recesses. Moreover, with their angulated visual axis and a wide viewing angle (opening like a funnel) endoscopy became strongly promoted as complementary tool[7] for various therapeutic middle ear intervention with specific indications[8,9,10] and even for CI surgery[11].
This study evaluates the potentials for transcanal tympanonoscopy comparing today´s most common endoscopic system (rod lense and fiberoptic digital camera systems and camera chip on the endoscope tip). In addition to the degree of visibility adressed by previous studies[12,13,14,15], we also evaluated the picture quality as subjectively perceived by the individual surgeon in order to define its role in image guided otologic therapy[16]. As an example, a potential future application of miniaturized chip on tip endoscope is tested in a pilot experiment simulating direct tunnel access as described with prototypes for robot assisted direct cochlear implantation1[17,18,19.20.21].

2 Methods

For transcanal diagnostic tympanoscopy (Fig 1), the conventional microscope OPMI Vario™ by Zeiss (Mic) and the following Karl Storz instruments have been compared: 2.7mm diameter 45° angled rod lense without (45) and with SPIES™ camera system (45S), 1.3mm diameter flexible sialendoscope (Sial) and a prototype of chip on tip (COT) camera system. For illumination a Xenon light source has been used and the middle ear was inspected raising a posterior based tympanomeatal flap. Videodocumentation of systematic tympanonscopy was recorded for the traditional landmarks in middle ear surgery[22,23,24] in the following order: 1) promontory:P, 2) entrance to the round window niche: RWN, 3) stapes footplate: SF, 4) sinus tympani: ST, 5) facial recess: FR, 6) epitympanon: ET (i.e. tensor tendon, incudo-malleolar joint), 7) Eustachian tube and supratubal air cells: ET and 8) hypotympanon: HT (Fig 1). Human temporal bones were used because no temporarily available artificial model could match with with it in the pre-experiments. The study was performed according to the ethical guidelines of the Swiss Academy of Medical Sciences on individuals who had provided written consent to dedicate their body to medical research and educational training purposes at the University of Bern, Switzerland on none-diseased formaline fixed human temporal bones . Data for Mic, 45 and 45S were recoreded by AIDA™ sytem. For Sial with digital filter A and for COT recording by the Tele Pack X™ system by Karl Storz has been performed. Reassessing the most important landmarks described in previous visualization studies[11,12,13,14], six ENT surgeons evaluated the still picture of each landmark and the dynamic film sequence of the tympanoscopy in randomized order on a 42’’ Wide View™ monitor by Karl Storz. The surgeons had a median experience in ear surgery of 5 years (range 2 to 23years) and rated the degree of visibility of the landmarks in % of the area of interest using still images (1920x1080pixels for microscope and rodlense systems; 1024x768 pixels for sialendoscope and COT). Second, overall picture quality was measured evaluating dynamic examination on film (1920x1080 pixels,29pps for microscope and rodlense systems; 640x480 pixels,25pps for sialendoscope and COT). Overall picture quality was defined as the individually perceived sharpness of the details rating their perception of sharpness with a vertical pencil mark on a scale from 0 to 10cm (0: unusable, 10: excellent picture quality).

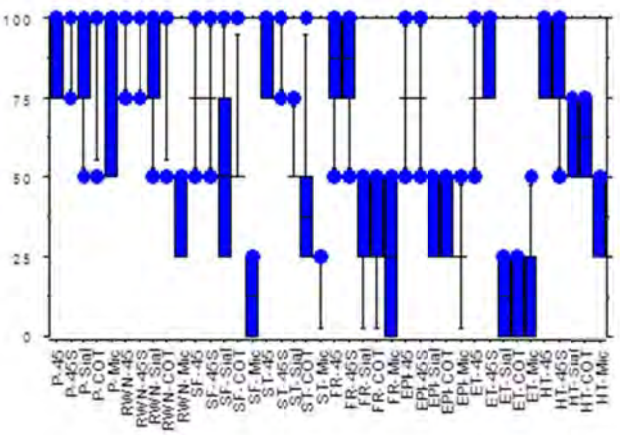
Figure 1 Transcanal view into left side ear after tympanic membrane removal with systematic tympanendoscopic evaluation of key microsurgical target structures



3 Results

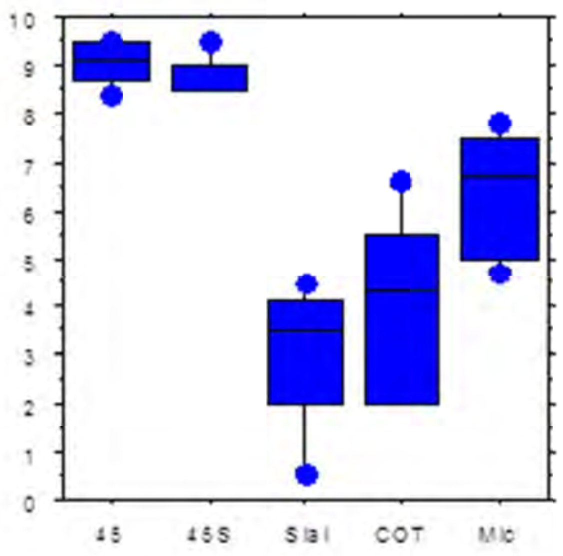
For middle ear landmarks visible with a straight line of sight along the external ear canal axis, most complete visualization was achieved by 45,45S and Mic systems. In hidden areas of the SF, ST, FR, EP and ET, endoscopes with 45° angeled visual axis were superior to the microscop and also to the microscope combined with indirect mirror inspection (SF,ST,FR,EPI,ET, HT).

Figure 2 Boxplot of degree of visualization in % for specific endoscopic system (45, 45S, Sial, COT, Mic) grouped according specific landmark inspected.



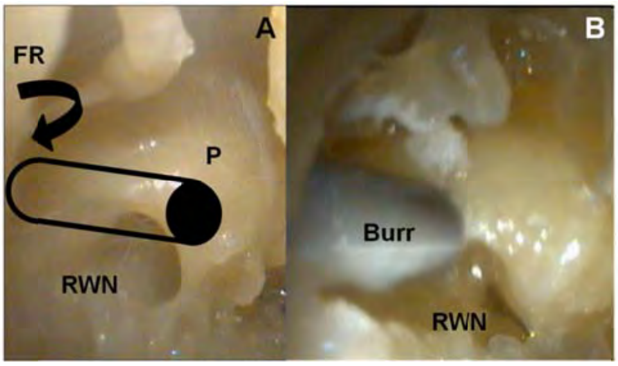
Picture quality was significantly dependent on the tympanoscopic system used ($p<0.05$, Friedman test). Although partial visualization of most middle ear structures was feasible with Mic, Sial and COT, the picture produced by these techniques were far from excellent and rated worst for the fiberoptic transmission by the Sial (Fig 3).

Figure 3 Individual rating of overall picture sharpness on dynamic film recordings of transcanal tympanoscopy. Box Plots of ratings on visual analogue scale ranging from 0 to 10cm (0: Absolutely unusable and 10cm:excellent).



For the RWN as surgical target structure for direct cochlear access , best compromise between extent of visualization and picture quality was provided by endoscope with 45° visual axis and by the COT. In a pilot experiment we used transcanal COT to monitor planned direct cochlar access (Image 1A) and to visualize the transtymanic progress of the burr along the direct cochlear access track (Image 1B). Wide Viewing angle and the large depth of focus allowed comprehensive monitoring of the transtympanic part of the procedure.

Image 1: Example of a wide field of view by miniaturized COT endoscope for visualization of the complete planned burr track (A) Example of wet lab simulation of robot assisted direct cochlear implant insertion (B) in a human temporal bone.



4 Conclusions

Previous studies described an advantage of a 30° and 70° endoscopes[25] compared to the microscope for complete visualization of important middle ear structures hidden in angled corners (ST, RF,SF..) from direct straight line of sight. These studies were often limited to one specific endoscopic system (rod lense or fiberoptic) and studied only the endpoint of degree of visualized area. Results of 1.7mm diameter 0°, 30° and 90° [13] as well as 4mm 0° and 2.7mm 70° [15]endoscopes or 0.4mm 0.7mm and 1mm fiberscopes[8] were thus methodologically difficult to compare. In addition to these previous "visualization studies"[12] we evaluated systematically a microscopic and four of the mainly used endscopic systems focusing especially also on picture quality.The degree of visibility for landmarks out off the straight line of sight was insufficient or unusable for the mirror image and microscope and only of restricted use for endoscopic systems with 0° visual axis (Sial, COT). The 45° angled endoscopes (45, 45S) provided best results and were much easier to guide through the middle ear space because of better orientation than previously described 70° or 90° endoscopes.

Best picture quality was either provided by the microscope when direct inspection without the need of a microscopic mirror was possible (P,RWN) or by the rod lens endoscopic systems. The 45 and 45S provided better picture quality especially for ST, SF, FR, EPI, HT. In addition inspection of very restricted regions of the EPI and ET, inspection with digitial image processing SPIES™ were perceived by some surgeons as better illuminated .

Future development will address smaller endoscopes with variable angle or flexible steerable tip as well as chip on tip solutions. These new developments will greatly facilitate otoscopic procedures as outlined in suggested indications and might well promote and support the applications of minimal invasive robot assisted ear surgery such as direct cochlear access cochlear implantation.

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